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The contribution of charcoal production to rural livelihoods in a semi-arid area in Kenya

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Abstract
Forest incomes in the form of both timber and non-timber forest products are an important source of livelihood for many communities in Africa. A major forest resource is charcoal, which contributes to the livelihoods of millions across the region. While incomes from charcoal are used to meet a wide spectrum of needs within rural livelihoods, the role of charcoal production on livelihoods of small-scale producers is not well understood. Therefore, we provide an example on the importance of charcoal on livelihoods in an agropastoralist community in a semi-arid region in Kenya. Based on a household questionnaire targeting 150 charcoal and 150 non-charcoal makers, as well as focus group discussions, we assessed the determinants for participation in charcoal production and developed a household typology based on charcoal income dependence. We also determined the role of charcoal in income equalization and poverty reduction. Our study shows that charcoal contributes about 20% of the household income in the study area. Gender, land size and the number of food-scarce months are the key determinants of participation in charcoal production. Based on the poverty analysis, we conclude that even though charcoal income does not lift the producers out of poverty, it can mitigate the impacts of poverty by reducing the poverty gap and poverty severity. Based on our findings, we recommend a multipronged approach to address sustainable rural livelihoods including a more explicit acknowledgement of charcoal production as a source of rural income. We also recommend broadening of the local livelihood base and a more active management of the woodland to ensure the sustainability of the income.

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Keywords Charcoal · Livelihoods · Income inequality · Forest incomes · Policy

1 Introduction

Over 1.6 billion people all over the world depend on forests for their livelihoods (Vedeld et al. 2007), and the role of forest resources on rural livelihoods has received an increased attention during the last decade (Angelsen et al. 2014). Forest resources include both timber and non-timber forest products (NTFPs) such as food, fodder, medicine, housing materials and fuel, including materials for charcoal production (Smith et al. 2017). Besides providing access to basic materials, forests contribute to total household and cash incomes, serving as subsistence income or an "economic buffer in hard times" (Kar and Jacobson 2012). A range of studies across the world indicate that forest incomes contribute between 12 and 75% of the total household income for rural households in sub-Saharan Africa, Nepal and China (Angelsen and Wunder 2003; Fisher 2004; Shackleton et al. 2007; Kamanga et al. 2009; Hogarth et al. 2013; Schure et al. 2013; Angelsen et al. 2014; Chhetri et al. 2014 Worku et al. 2014). Forest incomes are also important in reducing poverty and reducing income inequality (Fisher 2004; Babulo et al. 2009; Khundi et al. 2011; Worku et al. 2014), as forest income has the potential to act as crucial safety net preventing the poor from sinking deeper into poverty (Shackleton et al. 2008; Nielsen et al. 2012). However, several authors argue that dependence on forests may also turn into a poverty trap through degradation-driven impoverishment (Porro et al. 2015) or the lack of possibility for capital accumulation and income diversification in the household (Campbell et al. 2002; Angelsen and Wunder 2003; Adam et al. 2013).

A major forest and woodland resource in sub-Saharan Africa is charcoal, which contributes to the livelihoods of millions across the region (Jones et al. 2016; Smith et al. 2017). Charcoal production can range from a "one–off" occurrence during the year to more regular production, with charcoal income contributing up to 75% of the total household income (Schure et al. 2013). A number of studies have highlighted the role of charcoal production in household economies in Africa (see, e.g. Arnold et al. 2006; Ainembabazi et al. 2013; Butz 2013; Zulu and Richardson 2013). In general, income from charcoal serves as an important source of non-farm income for rural households, with low production investments (Zulu and Richardson 2013). Charcoal production is also seen as a diversification mechanism (Butz 2013). Diversification of rural livelihood portfolios with harvesting of environmental goods (including charcoal production) is a common practice in sub-Saharan Africa due to fluctuating climatic regimes (Eriksen et al. 2005), which has led to decreased food production (Shisanya 2011). Charcoal production is, for instance, used to generate cash income to buy grains, supplementary foods and other household commodities when food supplies run low in the off-season (Zulu and Richardson 2013).

The literature on charcoal production has only recently shifted from a largely negative and dominant narrative on environmental degradation (Hosier 1993, Chidumayo and Gumbo 2013; Ruuska 2013) to a more positive role of charcoal production for livelihoods of rural communities (Mwampamba et al. 2013; Zulu and Richardson 2013). This dominant narrative of charcoal and environmental degradation has been challenged by other authors (e.g. Mwampamba et al. 2013; Aabeyir et al. 2016) who argue that the regenerative capacity of woodlands is generally high and that woodland degradation is a post-harvest management issue. For example, Doggart and Meshack (2017) argue that it is possible to produce charcoal without degrading the woodland by protecting the harvested areas

from cultivation, grazing and fire, hence allowing natural regeneration. Other authors, for instance Jones et al. (2016), contest the idea that charcoal production is only a "last-resort type of livelihood activity" by the poor and highlights the different roles for charcoal within livelihood strategies for a case study in Mozambique. In general, there is a wide spectrum of charcoal producers ranging from small-scale producers to large-scale operators that produce charcoal commercially (Baumert et al. 2016). Several studies state that low-income groups are more dependent on charcoal, but higher-income groups receive higher charcoal revenues (Mamo et al. 2007; Kamanga et al. 2009; Schaafsma et al. 2012). The relative charcoal incomes for the poor are, however, often higher (Kamanga et al. 2009; Ndegwa et al. 2016). Overall, the role of charcoal production on small-scale producer's livelihoods is not well understood, especially with regard to its different roles within these livelihoods, varying from being a diversification strategy to a key source of income (Jones et al. 2016). To better understand the role of charcoal production within rural livelihoods in sub-Saharan Africa, context-specific information that differentiates between the diverse roles of charcoal production for different groups within communities is necessary. Assessment of the influence of charcoal production on equality and the potential as a "stepping stone" to reduce poverty is also important for a more nuanced and complete understanding of the role of charcoal production within rural livelihoods.

Currently, in the absence of coherent data on charcoal production by rural households and its role within livelihood strategies, the contribution of charcoal production to poverty alleviation is likely to be overlooked in policy formulation. Progressive policies which recognize the role of charcoal in poverty alleviation and rural development are rare in sub-Saharan Africa (Sepp 2008) and where they exist they lack coherence and are based on misinformation, myths and misconception (Neufeldt et al. 2015; Mwampamba et al. 2013). Under a coherent policy framework, all policies governing the charcoal sector would be compatible and mutually supportive along the entire charcoal value chain and across the key sectors, including forestry and energy (Sander et al. 2013). However, charcoal production and marketing are currently mainly relegated to the informal sector despite its importance as a source of livelihood and source of energy (Owen et al. 2013).

Energy policies in sub-Saharan Africa have ignored the potential of charcoal to contribute to livelihoods and energy needs (Neufeldt et al. 2015; Doggart and Meshack 2017). Specifically for Kenya, despite the availability of necessary policies and legislations for biomass energy development, the policies have not been fully operationalized or are largely ignored, and the sector still faces a myriad of challenges. For example in 2018, the County Government of Kitui effected a ban on charcoal production and transport within its borders (Gazette notice No. 936, January, 2018). This has negated all the objectives and gains on efforts to recognize, formalize and regulate charcoal as an important source of energy. Furthermore, the biomass energy policies are spread over multiple institutions leading to overlaps and a lack of harmonization (Wood and Garside 2014). This makes implementation, monitoring and enforcement of the charcoal production policy difficult. Therefore, for a better understanding of the context specific, the role of charcoal production on rural livelihoods is required for improved charcoal policies that take the rural poor into account (Smith et al. 2017).

Within this context, the aim of this study is to analyse the role of charcoal production within rural livelihoods, by looking at the factors determining the likelihood of involvement in charcoal production, the household income dependence on charcoal production and the role of charcoal income in poverty alleviation and income equalization for a semi-arid region in Kenya. In order to have a nuanced view of the different roles of charcoal production within livelihood strategies, we differentiate between different groups of charcoal

producers. Poverty alleviation and income equalization are analysed by comparing the poverty levels of charcoal producers with and without charcoal incomes. This study is not the first one on the role of charcoal income on rural livelihoods in Kenya. Ndegwa et al. (2016) conducted a similar study in Kitui where they used cluster analysis to group charcoal makers into three groups. Whereas Ndegwa et al. (2016) used an empirical approach for clustering charcoal producers, we used a predetermined group approach based on local knowledge. We used this approach as it is more consistent with realities in our study area.

Reliance on environmental goods for livelihood income is largely determined by household socio-economic characteristics (see, e.g. Angelsen and Wunder 2003; Adhikari et al. 2004; Fisher 2004). We hypothesize that greater dependence on charcoal for livelihood income is inversely related to education level, age and gender of the household head, land size holding, ownership of productive assets and distance to the main roads. Higher education is associated with less dependence on forest products as education provides better opportunities for off-farm income (Adhikari et al. 2004; Masozera and Alavalapati 2010; Heubach et al. 2011). For charcoal making, we expect younger people to be more involved since charcoal extraction requires a great physical strength (Garekae and Thakadu 2017). In addition, young people would be attracted to charcoal making to accumulate assets and establish their households (McElwee 2008; Lepetu et al. 2009). We hypothesize that more men than women would be involved in charcoal making due to social norms and gender roles (Amare et al. 2017). Charcoal making is hard, risky work and done almost always away from home. Where women operate away from home, they face a myriad of security challenges (Haile 1991, Muyanga 2005; Zulu and Richardson 2013). Land is an important capital asset in many rural areas for agricultural production; thus, we hypothesize that owning a big size of land and other productive assets may encourage a household to engage in crop and livestock production rather than engage in forest resource extraction (Babulo et al. 2008; Jain and Sajjad 2016). Assets play a key role in household's income and thus influence natural resource extraction (Nasar et al. 2016; Jain and Sajjad 2016). We hypothesize that households located near the main roads are likely to be more involved in charcoal production than households located far away. Distance to the roads is a proxy of access to charcoal markets as well as to the wood stocks (Schaafsma et al. 2012; Porro et al. 2015). Long distances to the nearest road hinder resource extraction by increasing labour and transportation costs (Mamo et al. 2007).

2 Methods

2.1 Study area

The study was undertaken in six villages in the Ndakani and Mutha locations of Kitui County in Kenya, 150 km east of Nairobi. A location is an administrative unit headed by a chief and consists of 2–3 sub-locations. Each sub-location comprises a number of villages. The population of the study area is 10,154 people in 1865 households (KNBS 2010) with an average density of 27 persons/sq. km (KCDP 2013). The study villages border Tsavo East National Park to the West and Kitui South Game Reserve (henceforth KSGR) to the East (Fig. 1). The local climate is classified as semi-arid with rainfall of below 750 mm per annum (Eriksen et al. 2005). The rainfall pattern is bimodal, consisting of "long rains" between March and May, while the "short rains" season occurs between October and December (Lasage et al. 2008). The vegetation of the study area is described as

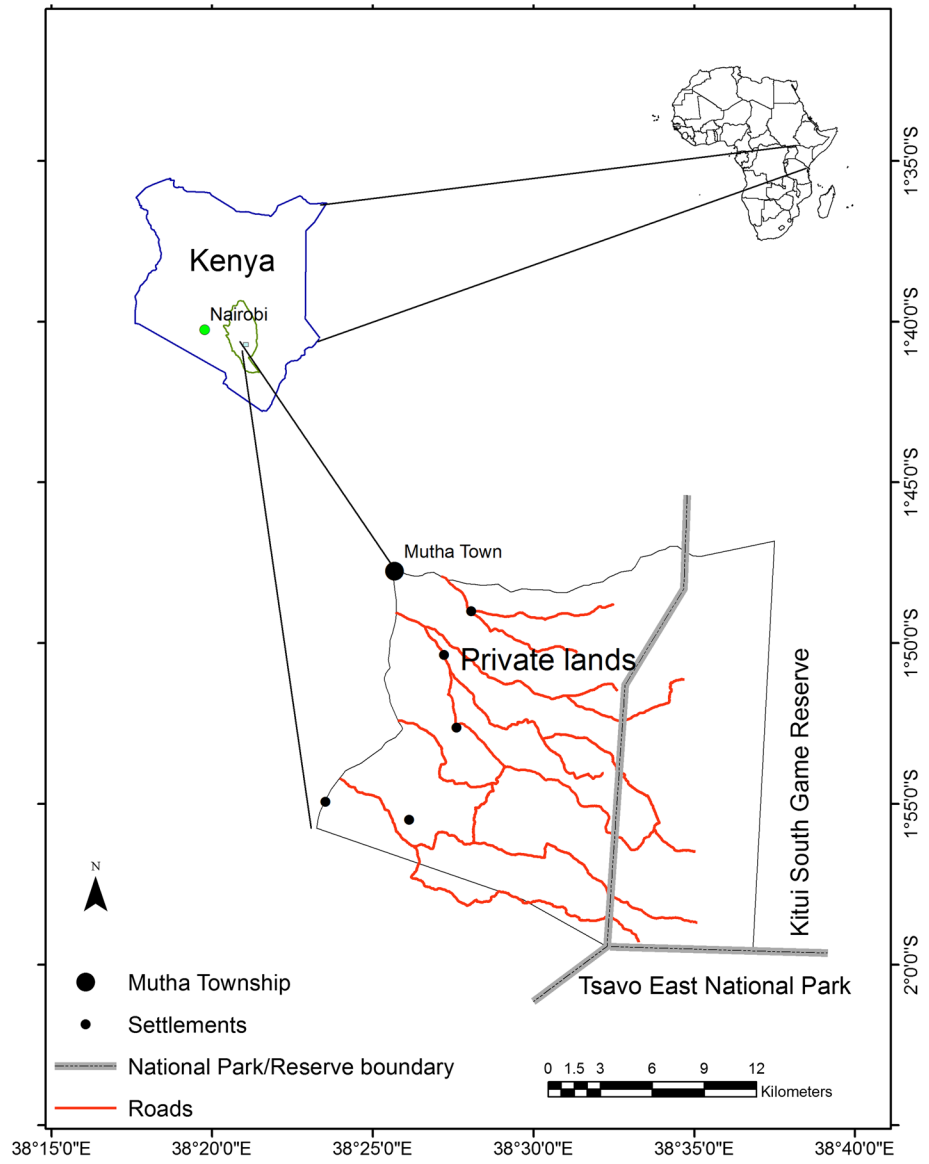

Fig. 1 Location of study area within Kenya

Acacia-Commiphora deciduous bushland and thicket within the Somalia-Masai ecoregion (Brink and Eva 2011). The study area is relatively small (442 km^2) and uniform in terms of soil type, topography and charcoal price dynamics (Jaetzold et al. 2007).

We selected the study area as it is located deep inside in the charcoal-producing area of Kitui County. Subsistence agriculture, pastoralism and charcoal making are three main economic activities in the study area (Kiruki et al. 2017). Poverty prevalence in the study area is 87% (KNBS 2010). As a coping strategy for the regular drought-related harvest

failures, residents have diversified their agricultural livelihoods from relying solely on rain-fed subsistence agriculture to charcoal production, selling of livestock, small trade, brick making and reliance on food aid (*murio)* and remittances (Eriksen et al. 2005; Kiruki et al. 2016). The dependence on charcoal for livelihood is high and has increased steadily since 1998 when charcoal making was first introduced, with currently up to 66% of the households engaging in its production (Kiruki et al. 2016). There is virtually no local demand for charcoal in the study area as charcoal use is a predominantly urban phenomenon, with charcoal mainly used for cooking. All charcoal produced in the study areas is therefore destined for big towns such as Nairobi and Mombasa (Kiruki et al. 2016). As the charcoal goes through the commodity chain, its value increases by 400% (KFS 2013).

The land in the study area consists of private and government lands (KSGR). Private land is owned through family lineages although formal titling has not been done. Shifting cultivation is practised within the family land holdings, which are generally a few kilometres apart. Charcoal making and livestock grazing take place both on private land and in the KSGR. Previous research has shown that both agriculture and charcoal making affect the structure and diversity of the vegetation in the study area (Kiruki et al. 2017).

2.2 Sampling and interview set-up

A purposive sampling of the households engaged in charcoal production and those not engaged was done. The charcoal-producing households were identified from village membership lists of the Mutha Charcoal Makers Association (MCMA) and village elders. From the MCMA membership lists, we identified 525 households who were resident within the study area. With the help of village elders, we were able to locate their villages, as well as non-charcoal-making households. Based on chronological numbering, we therefore obtained two household lists (for charcoal- and non-charcoal-producing households). Taking into account the population of the two groups in each village, we proportionately allocated our target sample size of 150 households for each household group within the six villages and took a random sample from each village. From each village, we sampled households from the chronological lists by generating random numbers from a hand-held calculator. As the research project had been introduced to the local residents by the area chief at an earlier stage, we faced no problem of non-response or refusal to be interviewed. Interviews were done in the local Kamba language by the first author and four research assistants who grew up in the study area. The interviews were conducted in May and June 2016 and lasted approximately 1.5 h. Prior to the main survey, the research team pretested the questionnaire to ensure questions were well understood by the respondents.

The interviews were based on a standard questionnaire with both open and closed questions, targeted at the household head. The questionnaire included quantitative questions on household characteristics, asset ownership, land utilization and ownership, income and costs associated with agriculture, livestock and charcoal making, incomes from businesses, employment, remittances and miscellaneous sources. Income and cost figures are based on the informants recall on all sources of cash and subsistence income for the previous year. This is a widely used survey technique for living standards assessment (McElwee 2010). Questions addressing a similar issue from different entry points were used as cross-check on answers provided, while field observations complemented the interview responses and helped to cross-check the authenticity of the information provided. For example, observing the nature of the family house (e.g. permanent, mud-walled or grass-thatched) was used as a quality control measure against the income reported.

We conducted two focus group discussions in the area in June 2017, which consisted of 26 individuals in total. The goal of the two focus groups was to give the researcher an insight into the charcoal industry, the reason behind participation in charcoal making and the extent of dependency on charcoal. The focus groups consisted of village elders, charcoal makers and individuals who were active in community activities, as identified by the assistant chief (lowest official in provincial administration in Kenya). Although discussions on charcoal with a "stranger" are approached with caution by many rural people in Kenya, the research team had the advantage of having been introduced earlier in a large public gathering in the study area by the local administrators and therefore could have an open discussion on the topic.

2.3 Estimation of household income and the contribution of different income sources

We used an income accounting approach to analyse the contribution of charcoal income to the total household income, in comparison with other income sources (Cavendish 1999; Fisher 2004; Babulo et al. 2009; Worku et al. 2014). Income includes the cash derived from market sales of products and local market value of products and services if they are consumed at household level. Cost of farm inputs and labour hired are subtracted from each income stream, and consequently, only net values are used in the calculations. Livestock income includes income from the market sales or market value of animals consumed at home minus livestock purchases and medicines. The major income categories of household income used in the analysis were agricultural income, livestock income, business income, selling of labour, charcoal income and remittances, especially from sons and daughters working far from home (see Table 8 in "Appendix" for a list of common goods and services and their value). In an income accounting approach, the cost of household labour is not included in the cost calculations (Tesfaye et al. 2011); therefore, the net income is inclusive of own labour costs.

2.4 Household characteristics determining charcoal-making likelihood and dependence on charcoal income

Using binary logistic regression, we identified the likelihood of a household taking part in charcoal production. The explanatory variables in the logistic regression analysis included gender, household size, age, education level, self-reported months of food scarcity, income (per adult equivalent), roof type and assets (such as bicycle, plough and land holding). The selection of explanatory variables is based on previous studies on charcoal participation. In the logistic regression, the dependent variable was the involvement in charcoal production (with 1 as a binary indicator for involvement in charcoal production, 0 for non-charcoal production). We used a receiver operating characteristic (ROC) curve to describe how well the logistic model predicts the binary outcome between charcoal makers and non-charcoal makers. The ROC curve is evaluated using the area under the ROC curve (AUC). An ideal model would have an AUC of 1 (Chuangchang et al. 2016).

We used ordinary least squares (OLS) regression to identify the household characteristics that explain the dependence on charcoal income. In the OLS regression, annual income from charcoal production was the dependent variable, with a selected set of socio-economic variables based on recent literature and field observations as independent variables (see Table 9 in "Appendix"). In the analysis, we used tropical livestock units (TLUs) as

units of equivalence for easier comparison of the value of livestock. The TLU conversion units for cows, goats and sheep are 0.7, 0.1 and 0.1, respectively (Jahnke 1982). We used distance to the main road to determine whether the location of a household has any effect on charcoal income. We used location of household as charcoal production sites keep on shifting depending on availability of tree species; thus, it is difficult to tie a charcoal maker to a specific site. Our study area is also relatively small, and we did not find any locational differences in charcoal prices.

2.5 Household classification based on charcoal dependence

There are no defined thresholds for classifying forest dependency (Jain and Sajjad 2016; Garekae and Thakadu 2017). Different authors have used various methods to define threshold levels for dependency. For example, Jain and Sajjad (2016) and Garekae and Thakadu (2017) used the average proportion of forest income for all households as a threshold, with households whose forest income is higher than this average being denoted as highly dependent. Those households whose income is lower than this are considered less dependent. Other authors classified households into mutually exclusive forest dependence groups based on local knowledge. For example, Babulo et al. (2008) classified households into four groups of forest income dependence ranging from less than 20% to greater than 60%, while Porro et al. (2015) used a threshold of 60% to denote high dependence on forest products.

In this study, we have used a combination of three criteria to delineate the dependence groups. Firstly, we used the knowledge from focus group discussion to understand the dependence levels as experienced by the village inhabitants. Secondly, we used the average proportion of charcoal income as a rough guide. The average proportion of charcoal income among households is 20%; thus, households whose income is above that were considered as highly dependent or specialist producers. Finally, we considered the need to have three more or less balanced groups. This resulted to charcoal groups whose proportion of charcoal income is $< 10\%$, 10–25% and $> 25\%$ to denote opportunist, undecided and specialist charcoal producers, respectively.

2.6 The role of charcoal in income inequality and poverty

We calculated the Gini coefficient to show the contribution of charcoal to household income and its equalizing effect. The Gini coefficient is widely used to measure income inequality between individuals (or households) by means of income distribution analysis (Yao 1997). We used the covariance formula to calculate the Gini coefficient (Bellù and Liberati 2006). The Gini coefficient can be described by Eq. (1) as:

$$G = \mathrm{Cov}(y, F(y))\frac{2}{\bar{y}} \tag{1}$$

where Cov is the covariance between income levels y and the cumulative distribution of the same income $F(y)$. The average income is $\bar{y}$.

The income equalization role of charcoal is described by comparing the Gini coefficient of household incomes with and without charcoal incomes. A reduction in the Gini coefficient value when charcoal income is included indicates that charcoal reduces income inequality among households (Mamo et al. 2007).

The Gini coefficient for a total income can be decomposed, so that the contribution of different income streams towards inequality can be identified (Babulo et al. 2009). There are numerous methods for Gini coefficient decomposition (e.g. Lerman and Yitzhaki 1985; Yao 1997; Reddy and Chakravarty 1999). We used the method by Lerman and Yitzhaki (1985), as this method is easy to interpret and allows for the computation of marginal effects on income source changes. Following Lerman and Yitzhaki (1985), the Gini coefficient for total income can be decomposed into different sources of income:

$$G = \sum_{k=1}^{k} R_k G_k S_k, \tag{2}$$

In Eq. (2), R_k is the Gini correlation between income from source k and the cumulative distribution of the total income, G_k is the Gini of the source income and S_k is the share component of income source k in the total income. Stand-alone G_k gives information on how equally or unequally distributed the income source is, while R_k shows what the correlation is between the income source and the distribution of total income (López-Feldman et al. 2007). Their combined term, $R_k G_k$, is also known as the pseudo-Gini coefficient, and it provides information on total income inequality in three ways: 1) if it is positive and larger than G, the source k is more unequal than total income, 2) if it is positive but smaller than G, source k decreases the total Gini coefficient, and 3) if it is negative, then income activity is mainly undertaken by low-income households (Li et al. 2011). This information can be used in welfare economics and policy interventions to decide which income sources to target in order to reduce income inequality within a given community. Finally, the response of the Gini coefficient to possible changes in income is analysed by calculating the effects of a 1% increase in each income source, while holding incomes from other sources constant. All calculations on the Gini coefficient were performed in Stata, using the "descogini" module (Lopez-Fieldman 2009).

2.7 Charcoal income and poverty alleviation

Inclusion or exclusion of charcoal income is expected to affect the number of people living below or above the poverty line. The most recent official poverty line available for Kenya equals Ksh 1562[1] per adult equivalent (pae) per month for rural areas (KNBS 2007). Per adult equivalent is the method of converting incomes of heterogeneous households into comparable measures, adjusted in order to account for differences in household size, composition and effects of economies of scale. This metric represents the minimum amount of money required to pay for a basket of goods meant to satisfy basic minimum food and non-food requirements. The pae was calculated following the method of Lanjouw and Ravallion (1995). The poverty line used in our analysis, Ksh 3823 pae per month for 2015, was estimated by correcting the official poverty line based on the consumer price index (CPI) for Kenya, which tracks the price movements for a minimum consumer basket. The review of poverty line figures using the CPI index is a common practice when no updated official figures are available (Reddy and Chakravarty 1999; Radeny et al. 2012).

We used the Foster–Greer–Thorbecke (FGT) family of indices (Eq. 3) to calculate the effect of charcoal income on poverty, following the method of Bellu and Liberati (2005).

[1] 1 US dollar = 93.5 Kenyan Shilling (December 2015).

The FGT indices were calculated to estimate the prevalence, depth and severity of poverty with and without incomes from charcoal and thus give an insight into the role of charcoal in poverty reduction. The FGT indices are popular because they are sensitive to income reduction among the poorest (Reddy and Chakravarty 1999).

$$\mathrm{FGT} = \frac{1}{N}\sum_{i=1}^{p}\left(\frac{z - y_i}{z}\right)^{\alpha} \tag{3}$$

Here N is the total population, P is the number of people below poverty line, z is the poverty line, y_i is each income below the poverty line and α is a weighting parameter viewed as a measure of poverty aversion. Usually a is a value between 0 and 2.

The FGT indices used with our analysis are: (1) the headcount index of poverty when $\alpha = 0$. This is poverty prevalence in the sample population, (2) the poverty gap index when $\alpha = 1$, which is how far below the poverty line the average poor household's income falls (poverty depth) and (3) the poverty severity index when $\alpha = 2$, which is an average of the squares of the poverty gaps relative to the poverty line.

3 Results

3.1 Sample characteristics

A total of 300 households were interviewed, which were equally divided between charcoal- and non-charcoal-making households. In total, 148 valid questionnaires for charcoal-making households and 147 valid questionnaires for non-charcoal-making households were obtained. The remaining five questionnaires lacked critical information and were not included in the analysis. The average household size is seven people for both charcoal and non-charcoal makers. The age of the respondents ranged from 20 to 74 years, with a mean age of 44.5 years. Thirty-one per cent of all households are female-headed, with large differences between charcoal- and non-charcoal-producing households (19% vs. 43%, respectively). Literacy levels are low among the respondents, with 99.3% having only attained primary education.

All the residents in the study area are agropastoralists. The major sources of incomes are farming, livestock keeping, charcoal making and small businesses with households earning an average of Ksh 37,348 and 25,935 pae for charcoal-making and non-charcoal-making households, respectively. The average farm holding per household is 4.56 ha, with cultivated area ranging from 0.28 to 8 ha (average 1.85 ha) for the non-charcoal-making households and 0.4 ha–4.8 ha for the charcoal-making households (average 1.3 ha). There are significant differences ($P < 0.05$) between household income, mean cultivated land area and livestock holdings (Tropical Livestock Units, TLU) between the charcoal-producing and non-charcoal-producing households (see Table 10 in "Appendix"). The main crops grown include mung beans (which is considered a cash crop), maize, cow peas and pigeon peas. The main types of livestock kept in the area include indigenous cattle, sheep, donkeys and goats. Agricultural production is low and unpredictable. For example, in 2016 the harvests for the region were 163 kg/ha for maize, 56 kg/ha for mung beans, 146 kg/ha for sorghum and 125 kg/ha for millet (Milelu et al. 2017), which are low compared to higher rainfall areas. The average livestock holding is 4.1 and 2.1 TLU for the non-charcoal-making and charcoal-making households, respectively. Due to low and unpredictable agricultural production, food scarcity is a permanent feature in the study area, with households

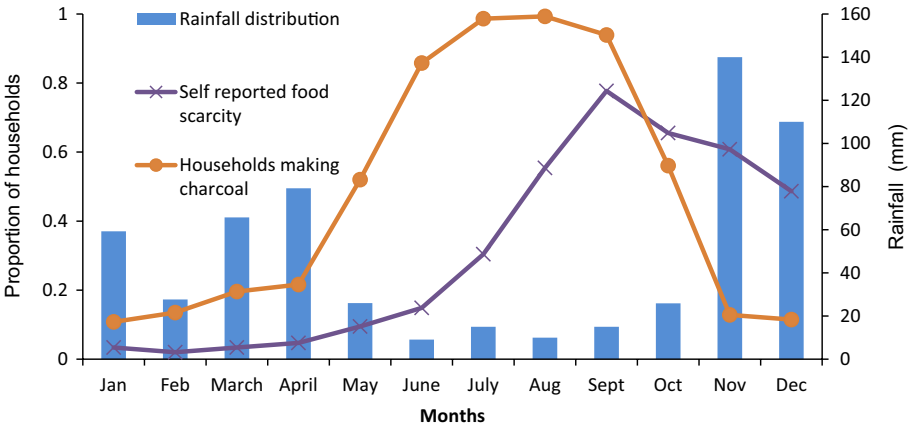

Fig. 2 Relationship between rainfall distribution, charcoal making and self-reported food scarcity in Kitui County, Kenya. The rainfall data are adapted from Ndathi et al. (2011)

reporting substantial food-scarce months per year for the charcoal-making (4 months) and non-charcoal-making households (3 months).

Access to water both for human and for livestock use is a big challenge in the study area as only 6% of the residents have access to water. During prolonged droughts, residents walk up to 15 km to access water (Lasage et al. 2008). Initially, all households used donkeys to carry water over the long distances, but nowadays enterprising young men vend water using motorbikes with 20 litres jerrycan fetching up to Ksh 30 (Afullo et al. 2011).

Historically, the area enjoyed two crop-growing seasons, namely March–May and October–December, but this is no longer the case because of the changing climatic patterns. Currently, October–December is the main crop-growing season. Charcoal making peaks between April and October, which are the dry months, with up to 100% of the sampled charcoal-making households engaging in charcoal production in July–August (see Fig. 2). Charcoal production drops again when rainfall increases. While March–April still has a considerable rainfall on average, this is often unreliable, therefore leading to increased charcoal making.

For the charcoal-producing households, twenty-two per cent of their income is from charcoal, while farming and livestock comprise 34% and 37% of the incomes, respectively. Most of the charcoal income (57%) is used to pay for food, school fees and clothing, while 16% of charcoal income is used to acquire livestock assets. Buying water, paying for health costs and others take up the remainder (Fig. 4 in "Appendix"). For non-charcoal-producing households, livestock is the main source of income (48%) followed by farming (30%) and business (13%) (Fig. 3).

3.2 Charcoal-making process

All the charcoal in the study area is produced by the use of surface earth mound kilns. A kiln is an insulated chamber for wood carbonization made by covering a wood pile with herbaceous material and soil (Chidumayo and Gumbo 2013; Kiruki et al. 2016). Charcoal making involves felling of preferred tree species such as *Strychnos spinosa, Cassia*

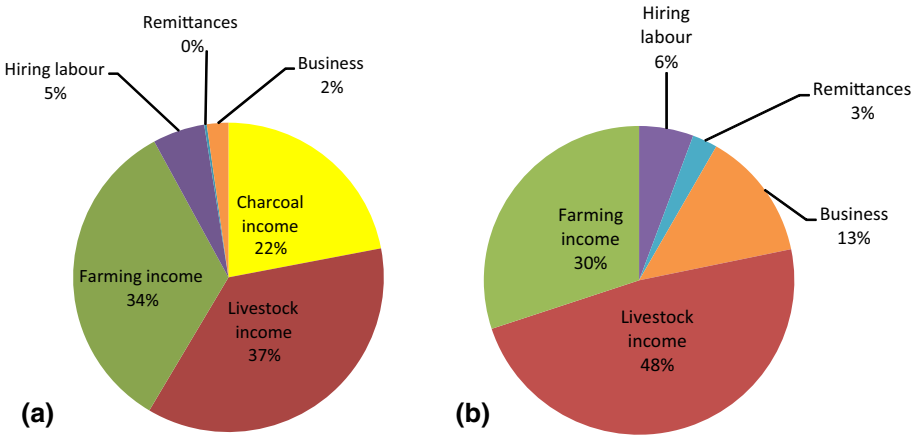

Fig. 3 The average household income sources that contribute towards total household income for: (a) charcoal-producing households and (b) non-charcoal-producing households

Table 1 Determinants of charcoal production participation in Kitui County

Predictor variable	B	Wald χ^2	*P*	Odds ratio	Probability
Constant	−2.118	0.481	0.000	0.120	0.1071
Gender	1.892	0.304	0.000	6.631	0.8689
Land size	−0.066	0.017	0.000	0.936	0.4834
Food-scarce months	0.135	0.058	0.020	1.145	0.5338
Solar kits	1.009	0.345	0.003	2.742	0.7328
Plough	0.822	0.287	0.004	2.275	0.6946
Nagelkerke R^2	0.35				

abbreviata, Boscia coriaceae and Balanites aegyptica (Kiruki et al. 2017). Charcoal production has been going on in the study area since 1998 (see Kiruki et al. 2017 for more details).

Due to selective cutting of preferred species, a single kiln usually has a "catchment" distance of several metres around it depending on the density of the preferred tree species (Kiruki et al. 2016). Majority of charcoal making happens on private lands bordering KSGR and inside the KSGR. The distance a charcoal maker covers to the kiln site depends on gender and the type of the charcoal maker. Women usually make charcoal within a radius of 1.5 km from their homes, while Specialists make charcoal far from their homes where there are more woodlands available for charcoal making (Kiruki et al. 2019).

3.3 Determinants of charcoal-making participation

We used a logistic regression to analyse the determinants of charcoal-making participation on a household level (Table 1). The results show a positive and significant effect for the gender and food scarcity coefficients, indicating that when controlling for other factors, male-headed households are 6.6 times as likely to involve in charcoal production than

Table 2 Determinants of household charcoal income in Kitui County

Explanatory variables	Coefficient	Std. error	Standardized coefficients	*t* value	*P* value
(Constant)	3.041×10^{4}	6.044×10^{3}			0.000
Age	-2.814×10^{2}	8.122×10^{2}	−0.17	−2.21	0.028
TLU	3.506×10^{3}	1.271×10^{2}	0.33	4.31	0.000
F (2, 142) = 11.25, Adjusted R^2 = 0.125					

Table 3 Determinants of relative charcoal income in Kitui County

Explanatory variables	Coefficient	Std. error	Standardized coefficients	*t* value	*P* value
Constant	1.33×10^{-1}	5.0×10^{-2}		1.783	0.077
Dist. to all roads	9.574×10^{-5}	0.000	0.244	3.124	0.002
Dis. to main road	-1.049×10^{-5}	0.000	−0.189	−2.437	0.016
TLU	-3.4×10^{-2}	9.0×10^{-3}	−0.309	−3.558	0.001
Oxen plough	7.4×10^{-2}	3.2×10^{-2}	0.199	2.301	0.023
Age	3.0×10^{-3}	1.0×10^{-2}	0.155	2.015	0.046
Gender	-7.0×10^{-2}	3.5×10^{-2}	−0.153	−1.989	0.049
F (6, 137) = 6.6, Adjusted R^2 = 0.23					

female-headed households. Furthermore, charcoal-producing households are 1.1 times as likely to turn to charcoal production as food scarcity increases. Charcoal makers are also more likely to have solar panels or a plough. Land size has a negative but significant effect on charcoal making. Households with larger sizes of land are less likely to be involved in charcoal making as increasing land by 1 unit decreases the likelihood of making charcoal by 0.936 (Table 1). Other socio-economic indicators did not distinguish between charcoal makers and non-charcoal makers. The Nagelkerke pseudo-R^2 indicates a reasonable good fit of the model which is confirmed by the area under the curve of the receiver operating characteristic (ROC) of 0.8 indicating a good accuracy level (Swets 1988).

3.4 Determinants of charcoal income dependence and household typology

We used OLS regression to test the relationship between charcoal income and relative charcoal income (dependent variable) to different socio-economic variables (for the independent variables, see Table 9 in "Appendix"). Charcoal income is the net monetary value of charcoal sold by a household within a period of 1 year, while relative charcoal income is the proportion of total household income earned from charcoal. In the regression analysis, only the independent variables whose coefficients were significant were considered as robust enough to explain households' dependence on charcoal. The results show that charcoal income is significantly related to age and quantity of tropical livestock units (TLUs; Table 2). Age has a negative coefficient, which indicates a decreasing charcoal income with increasing age of the household head. Together, these variables explain 13% of the variation in household charcoal income.

Relative charcoal income is significantly related to the distance to main and minor roads, age, magnitude of tropical livestock units, presence of a plough and gender (Table 3). Distance to the main road, TLU and gender have a negative coefficient, indicating that relative charcoal income decreases as distance to the main road and TLU increase. Charcoal income also decreases if your gender is female. Overall, the variables explain 23% of the variation in relative charcoal income among the households (Table 3).

3.5 Household typology and livelihood options

We classified our household samples into four household types based on the proportion of charcoal income in relation to total household income. The first household type relies on agriculture, livestock keeping and business activities for their livelihoods. We designate them as Conventionalists. The second household type, Opportunists, has charcoal contributing up to 10% of their total income. This group is least dependent on charcoal income, and they are engaged in charcoal making on ad hoc basis while retaining the traditional sources of income as their major source of livelihood. The third household type, designated as Undecided, has charcoal contributing to 10–25% of their total income. This group make relatively modest incomes from all sources. The fourth household type has charcoal contributing ≥ 25% of their total income and is therefore named Specialists. All the households interviewed were living in the study area. We did not encounter any migrant labour force in the study area. However, some of the interviewed households had returned home from Chyulu Hills in the neighbouring Makueni County about 120 km south-west of the study area, and they brought with them charcoal-making skills (Kiruki et al. 2016).

Table 4 summarizes key attributes of the groups. There is a significant difference in charcoal income between the Opportunists, Undecided and the Specialists ($P < 0.05$). For all the household types, there is no significant difference in incomes from selling labour and remittances (Table 4).

3.6 Effect of charcoal on income distribution

Charcoal income has an equalizing effect on the income distribution among the producing households in Kitui, as the Gini coefficient (0.35) among charcoal-producing households is lower compared to non-charcoal-producing households (0.39; Table 5). Among the charcoal-producing households, livestock, honey and business incomes are the main sources of income inequality, as their pseudo-Gini is larger than the total income Gini. Livestock and farm incomes have high Gini correlation coefficients among charcoal-producing households, which imply that these two activities favour high-income households. The income share of charcoal is almost similar to its percentage contribution towards income inequality (19.7%), implying that it does not contribute to income equality. Among the non-charcoal-producing households, livestock and business incomes are the main sources of income inequality (pseudo-Gini > total income Gini). Those incomes also have high Gini correlation coefficients, implying that they favour high-income households. Livestock, with an income share of 0.47, contributes to 54% of the income inequality, thus being a major source of income inequality among non-charcoal-making households (Table 5).

A 1% increase in charcoal, honey, labour and business incomes will lead to no change in the Gini coefficient (Table 5, final column), while a similar income increase leads to most impact for livestock income. For livestock, the Gini coefficient will increase by 12.1%, increasing income equality. Among the non-charcoal-producing households, increasing

Table 4 Characteristics of the household typology

Socio-economic characteristic	Household typologies				Statistics		
	Conventionalists ($n=147$)	Opportunists ($n=54$)	Undecided ($n=54$)	Specialists ($n=40$)	Std.dev.	F	P
Average charcoal income (Ksh)	–	5285	10,216	37,126	21,845	41.7	0.000
Av. Income from livestock	35,969	50,017	16,201	16,494	48,439	13.6	0.00
Av. income from farm	23,943	29,520	23,402	17,145	24,447	6.0	0.001
Av. income from business	1598	1752	2622	0	25,922	7.0	0.00
Av. income from remittance (Ksh)	2918	2498	1740	1297	5641	1.17	0.321
Av. income from selling labour	6322	5174	3062	3192	1318	0.635	0.593
Av. total income	119,956	99,418	60,863	78,881	73,789	8.14	0.000
Cultivated land (ha, mean)	1.84	1.55	1.0	1.34	3	7.6	0.000

Table 5 Gini decomposition of charcoal- and non-charcoal-producing households, indicating the marginal effects when there is a 1% increase in income from a given source, while other incomes are constant

Income sources	Income share *(Sk)*	Gini coefficient *(Gk)*	Correlation with total income distribution *(Rk)*	Pseudo-Gini coefficient *(Gk*Rk)*	Absolute contribution to inequality *(Sk*Rk*Gk)*	Share in total income inequality *(Sk*Gk*Rk/G)*	Relative concentration of income source (Gk*Rk/G)	% change in Gini coefficient upon 1% increase in income sources *(Sk*Gk*Rk/G)-Sk*
Charcoal makers								
Livestock	0.36	0.57	0.81	0.46	0.167	0.48	1.34	0.12
Farming	0.30	0.40	0.64	0.25	0.08	0.22	0.73	−0.08
Charcoal	0.20	0.57	0.62	0.35	0.07	0.20	1.00	0.00
Honey	0.01	0.92	0.49	0.45	0.21	0.59	1.31	0.00
Labour	0.05	0.79	0.41	0.32	0.11	0.30	0.93	−0.00
Firewood	0.05	0.26	0.23	0.06	0.00-	0.83	0.16	−0.04
Remittances	0.02	0.84	0.23	0.19	0.00-	1.33	0.56	−0.01
Business	0.02	0.95	0.54	0.51	0.01	2.94	1.47	0.01
Total income		0.35						
Non-charcoal makers								
Livestock	0.47	0.52	0.85	0.44	0.21	0.54	1.14	0.07
Farming	0.29	0.40	0.63	0.25	0.08	0.19	0.66	−0.10
Honey	0.01	0.92	−0.05	−0.05	−0.00	−0.00	−0.13	−0.01
Labour	0.06	0.84	0.38	0.32	0.02	0.05	0.83	−0.01
Firewood	0.02	0.26	0.24	0.06	0.00	0.00	0.16	−0.01
Remittances	0.03	0.80	0.40	0.32	0.00	0.02	0.83	−0.00
Business	0.13	0.85	0.67	0.58	0.08	0.20	1.51	0.07
Total income		0.39						

Table 6 Poverty indicators based on 148 charcoal-producing and 147 non-charcoal-producing households in Kitui, Kenya

Category	Headcount poverty %	Poverty gap %	Poverty severity %
All respondents	81	41.4	26
Non-charcoal makers	75.5	35.5	21.7
Charcoal makers (with charcoal income)	87.1	54.9	30.1
Charcoal makers (minus charcoal income)[1]	93.9	56.9	39.6

Table 7 Poverty indicators among different groups of charcoal-producing households in Kitui, Kenya

Household type	Category	Gini coefficient	Headcount poverty%	Poverty gap%	Poverty severity%
Opportunist households	With charcoal	0.28	81.4	35.7	19.6
	Without charcoal	0.29	88.8	38.6	21.8
Undecided households	With charcoal	0.32	96.2	58.4	39.1
	Without charcoal	0.32	96.2	64.5	45.9
Specialist households	With charcoal	0.38	82.5	47.7	32.1
	Without charcoal	0.42	97.5	71.1	51.1

income from livestock and business by 1% will lead to the increases in Gini coefficient by 7%, while an increase in all other sources will lead to decrease in Gini coefficient (Table 5).

3.7 The role of charcoal incomes in poverty reduction

Based on the FGT family of indices, we find high poverty rates (81%) among all households. However, poverty is more prevalent among the charcoal-producing households. Inclusion of charcoal income reduces the headcount poverty from 93.9 to 87.1% and the poverty severity from 39.6 to 30.1% (Table 6).

Among the charcoal producers, poverty is highest among the Undecided households. The Specialists have the highest values for both the poverty gap and poverty severity indices when charcoal income is excluded, indicating the importance of charcoal in preventing households from sinking deeper into poverty (Table 7).

4 Discussion

Charcoal making in the study area occurs on woodlands in both private land and in KSGR. Charcoal making on private land is mostly done by family members with the consent of the household head. Non-family members can only access trees for charcoal making on private land through negotiated arrangements with the household head. The most common arrangement is "produce and share" where the land owner and the charcoal producer agree on a ratio on which to share the produced charcoal. There is easy but illegal access to wood resources for charcoal production in KSGR. Any able person from around the study area can easily access the game reserve and make charcoal. The KSGR is owned by County

Government of Kitui which is supposed to manage it in conjunction with Kenya Forest Service and Kenya Wildlife Service. However, in reality, no such management exits and the area can be regarded as open access (Kiruki et al. 2017).

Accessibility to forest resources is mainly determined by the charcoal maker type and gender. The Undecided and the Specialists generally carry out charcoal making both in the private land and in the KSGR. Women mainly consider making charcoal in areas near their homesteads so that they can attend to children and other household chores. In addition, KSGR is considered not safe for them (Kiruki et al. 2019). Women have been known to suffer attacks as they collect wood fuel (Haile 1991; Wan et al. 2011).

Environmental factors greatly affect the composition, diversity and structure of charcoal-producing woodlands. Soil characteristics, topography, precipitation, temperature and drought not only influence woodland plant species composition (Randriamalala et al. 2016), but also determine early woodland regeneration, sapling survival and growth (Príncipe et al. 2014).

Drought directly influences the quantities of charcoal produced as it was observed that during drought years more charcoal is produced to cater for reduced agricultural income (Kiruki et al. 2019). Agricultural production in the study area has been on a downward trend due to a declining rainfall (Mosberg and Eriksen 2015). This has increased the dependence on charcoal for livelihoods (PISCES 2010; Eriksen et al. 2005). The results presented in this paper provide a snapshot on the importance charcoal making at the household level at the time of the study, which is a characteristic of survey studies. The dynamics of how woodland resources have been changing in the study area over time is well covered by Kiruki et al. (2016, 2017).

4.1 Income from charcoal and the local livelihood context

Charcoal income comprises approximately 20% of the total household income in the study area. This finding is within the range of other forest-based income studies in similar settings in sub-Saharan Africa (e.g. Mamo et al. 2007; Babulo et al. 2009; Kamanga et al. 2009). In contrast, higher charcoal contributions of between 38 and 75% of the total household income have been reported for the Democratic Republic of Congo (Schure et al. 2013), and charcoal is named as the biggest source of income for all producers in southern Malawi (Smith et al. 2017). Compared to these situations, the contribution of charcoal incomes is rather modest in our study area. In spite of its relatively modest role, charcoal incomes are an important part of livelihoods as up to 57% of the charcoal proceeds are used to pay for basic needs, notably food. This confirms that charcoal income just like income from other non-timber forest products income is used for subsistence purposes. This is not surprising as the charcoal makers have significantly smaller cultivated fields as compared to the non-charcoal makers but have similar family sizes and dependency ratios.

Charcoal-producing households are likely to experience food shortages for more months in a year, as evidenced by our logistic regression analysis. As explained by one charcoal producer, food scarcity is a major driving force of charcoal making, especially when rains and harvests fail. He said "*We have experienced inadequate rains for long and our stores are empty, we need to eat and our children need to attend school, charcoal making is our saviour for now*". According to informal interviews with villagers, rainfall has been irregular since the El Nino rains of 1997, leading to frequent crop failures. Using proceeds from charcoal to pay basic needs has been reported widely in sub-Saharan Africa (Butz 2013; Schure et al. 2013; Smith et al. 2017).

Non-charcoal makers have much more livestock than charcoal makers (see TLU, Table 10 in "Appendix"). It is these assets which they sell to buy food in case of poor

yields. Non-charcoal-making households can accumulate such assets because they have much higher incomes (Table 4) as compared to charcoal-making households. It is also likely that non-charcoal makers have higher savings which they can draw on to buy food to compensate for poor yields instead of turning to charcoal making. Selling livestock and drawing on savings are documented as among the coping strategies used by rural households in times of disasters such as droughts (Ellis 1998; Roncoli et al. 2001).

Besides experiencing food shortages for more months in a year and having less access to land, the charcoal-producing households in our case study area are generally male-headed and have assets such as solar panels and oxen plough. Our hypothesis that education level is a determinant of charcoal production was not confirmed. This is because virtually all the charcoal makers have basic education, which does not offer them opportunities to engage in formal employment. The predominance of men in charcoal production confirms our hypothesis of a positive relationship between gender (male) and greater charcoal production dependency, which was also observed by Schaafsma et al. (2012). This might be due to its physically demanding nature and the need to work away from home. A possible explanation for ownership of assets such as solar panels and oxen ploughs is those households who engage in charcoal making receive this income in lump sum, making buying certain assets possible. As the case study area is outside the electricity grid, solar kits are important for charcoal makers not only as a lighting source but also for mobile phones used for communication with charcoal brokers. A plough is an important agricultural equipment, which can also shorten the time it takes to attend to agricultural activities, thus leaving more time for other activities such as charcoal making. Charcoal income has been known to be used to purchase assets, but the extent is unknown due to the lack of long-term data (Jones et al. 2016). We did not encounter situations where Specialists have invested charcoal income to cultivate bigger farms, buy modern machinery and pay for farm inputs or labour. While Specialists make more money from charcoal, they have the least total income and up to 57% of charcoal income is used for subsistence purposes and only 16% of the charcoal income was used to buy assets. We could not confirm our hypothesis that higher ages are correlated with higher charcoal incomes, as our results show a negative relationship between age and household income and a positive relationship between age and relative charcoal income.

Interestingly, the study finds that land size is a determinant of charcoal production, with households having smaller sizes of land more likely to engage in charcoal production.

However, this finding should be treated with caution as agricultural production is low due to lack of rains (e.g. see Milelu et al. 2017). Households on average have only utilized one-third of their total land holding for crop growing (Table 10 in "Appendix") leaving the rest as fallow. This indicates that there is no shortage of land for cultivation. During the interviews, charcoal makers pointed out that the main reason they engage in charcoal making is not due to the lack of land to grow crops, but due to the impact of drought leading to crop failure as well as lack of alternative sources of income, lack of other job opportunities and poverty. Our focus group discussions also did not indicate land as being an indicator of wealth, meaning that land is not highly valued and thus not in demand due to low agricultural production. However, bigger land sizes may also provide more opportunities to engage in other farm activities such as livestock keeping. This may explain why households having smaller sizes of land are more likely to engage in charcoal production as they keep less livestock compared to those with bigger land holdings. Although there were no indications that scarcity of land was driving younger households to involve more in charcoal production in the study area, studies elsewhere show that people without access to land engage in charcoal production in communal lands (Belay et al. 2015). Khundi et al. (2011) observed that charcoal-producing households in Uganda have less land, are likely

to be male-headed and have less productive assets compared to non-charcoal-producing households, but there was no evidence linking land size to charcoal production. Our logistic regression result with respect to land size is also contrary to studies of Schaafsma et al. (2012) in Tanzania and Khundi et al. (2011) in Uganda, who found that the size of land holding does not determine whether one engages in charcoal production or not.

Our regression results show that relative charcoal income is significantly ($P < 0.05$) and negatively related to distance from a charcoal producers' house to the main road traversing the area. This confirmed our hypothesis of a negative relationship between charcoal incomes and the distance to the main road, which was based on previous studies regarding forest incomes by Mamo et al. (2007) and Schaafsma et al. (2012). The negative relationship between distance to the main road and charcoal income is explained by the fact that a big number of charcoal makers travel to the kiln sites, which are usually far from their homes near the main road (4 h walking on average, charcoal producers, pers com.). Another observation was that people living far away from the main road have relatively larger farms and concentrate more on livestock keeping for livelihoods.

4.2 Household typologies and dependence on charcoal

Charcoal production is an important source of livelihood in the case study area, with 66% of the households currently being involved in charcoal production (Kiruki et al. 2016). The importance of charcoal to the local livelihoods in different household types is reflected in that fact that charcoal forms part of the "local lingo", referring to specific occupations, assets and situations. For instance, for assets that are bought with money derived from charcoal, such as a bicycle it is (known as *baiskeli ya makaa*). However, the role and importance of charcoal income vary across the household types.

Non-charcoal-producing households earn significantly more than charcoal-producing households. Furthermore, there is a clear trend of average income reduction as dependence on charcoal income increases, thus qualifying our hypothesis that greater dependency on charcoal is associated with lower total income (see Fig. 5 in "Appendix"), meaning that the dependence on charcoal increases gradually from the Opportunist to the Specialist groups. The four household types are significantly different in all the socio-economic characteristics except income from remittances and selling labour (Table 4). The large standard deviation is an indicator of large variability within the sample households. This indicates the variability of income sources in rural households (Illukpitiya and Yanagida 2008). Furthermore, the data used are for only 1 year and not for a long-time average.

The Opportunists make significantly less income from charcoal as compared to the Undecided and Specialists ($P < 0.001$) and spend the least time in charcoal making. Among the Opportunists, the role of charcoal can be seen as that of a "gap filler" in their income matrix, as their main income comes from agriculture, livestock and selling labour. They produce charcoal once or twice a year to get cash to offset a pressing need and can therefore be considered as ad hoc producers. Using forest incomes to offset emergency needs has been well recorded in the literature, for example, by Smith et al. (2017).

Our household classification method differs from that of Ndegwa et al. (2016) because of the differences in study objectives. Whereas our objective was to analyse the role of charcoal production within rural livelihoods, Ndegwa et al. (2016) focused more on exploring the heterogeneity of rural charcoal producers. Our study focused on the influence of charcoal on household income, while Ndegwa et al. (2016) took charcoal income as one of the many income factors. The resulting clusters are therefore determined by the other

sources of income as well. Therefore, differences emerge such as that our Opportunist producers are less dependent on charcoal income, while the small-scale producers in Ndegwa et al. (2016) are highly dependent on charcoal. In our case, there is no relationship between total income and charcoal producer type, while in Ndegwa et al. (2016) total income increases from small-scale producer to large-scale producers.

For Undecided households, charcoal production is a seasonal economic activity just like crop growing and provides seasonal income in the dry season (Arnold et al. 2006). Their low average income can be attributed to the fact that they lack specialization on any enterprise and hence miss opportunities to maximize income (Deininger and Olinto 2001). Specialists are full-time charcoal producers and focus little on other forms of income such as small businesses, but instead produce charcoal on a large scale. Interestingly, the Specialists have a higher mean cultivated area than the Undecided households (1.34 vs. 1 ha), which was an unexpected outcome. A possible explanation is that these bigger cultivated areas are a consequence of charcoal making, as bigger parcels of woodland may be opened with charcoal making as the main goal.

Most Specialists produce charcoal in camps located in KSGR (so-called *itheo*), where there are possibilities of higher production due to a higher concentration of trees. This is the group which is at the greatest risk of losing livelihoods in case of changing legislation or due to increased woodland degradation, considering that most of the income from charcoal is used to pay for basic needs. Charcoal production is illegal in KSGR, and they have to contend with the sporadic risk of being arrested, which is a common occurrence in woodland areas (e.g. Chidumayo and Gumbo 2010; Smith et al. 2017). For example, the first author witnessed tens of charcoal makers being forced out of KSGR in June 2015 by security forces. Apart from risking arrest, they also risk attacks from Somali and Orma herders as a reprisal whenever there is a conflict between the herders and farmers, which is a regular occurrence in the area (CGK 2015). Therefore, for this group charcoal can be seen as a "last-resort type of livelihood activity", considering that they can risk it all to earn some charcoal income.

Our results confirm the role of charcoal income in the study area is different for our three identified groups. The Opportunists have a higher mean income than the larger producers, who are highly dependent on charcoal income and have the least income from farm, livestock and business. These findings therefore bring into question whether higher-income groups benefit more from charcoal as is the case with other forest incomes (Mamo et al. 2007; Kamanga et al. 2009; Schaafsma et al. 2012). Our results suggest that the bigger charcoal makers benefit more from charcoal despite being among the lower-income groups.

4.3 Charcoal income, poverty and inequality

Poverty is prevalent in the study area, with charcoal makers having a higher poverty prevalence rate than non-charcoal makers (87.1% vs. 75.5%). Charcoal incomes play an important role in poverty reduction in the study area, as it reduces the prevalence of poverty rates by 7% among all charcoal makers (up to 15% for the Specialists). Our hypothesis that charcoal production slightly reduces poverty is therefore confirmed, although the effect is modest. The ability of charcoal income to reduce poverty prevalence rates has also been reported in Uganda (Khundi et al. 2011) where a reduction in poverty by 14% was reported for those households engaged in charcoal production.

However, the future of charcoal production and the derived benefits for poverty reduction are uncertain as the woodlands in the study area can only sustain the current levels of charcoal production on the short term, but not on the long term (Kiruki et al. 2019), meaning that

its equalizing effect cannot last for long. Furthermore, only 16% of the charcoal income was used to buy and accumulate assets such as livestock or invested in alternative non-land-use livelihood sources (Fig. 4 in "Appendix"). This was due to high consumption rates of charcoal income occasioned by frequent crop failures. Charcoal is, just like any other non-timber forest product, a low return activity to the producer, and thus, it takes a lot of hard work to earn some substantial income (Angelsen and Wunder 2003). In our case, charcoal production has some characteristics of a poverty trap, due to low returns on labour (Angelsen and Wunder 2003).

Regarding the role of charcoal as a factor in reducing income inequality between charcoal-producing and non-charcoal-producing households, we found that charcoal-producing households had slightly more equal incomes as compared to non-charcoal-producing households (0.35 vs. 0.39). Furthermore, an increase in charcoal income has zero relative marginal effects (Table 5). The equalizing effect of charcoal incomes is comparable to what has been reported in other forest income studies (e.g. Vedeld et al. 2007; Kamanga et al. 2009; Jagger 2012; Khundi et al. 2011).

4.4 Limitations of the study

While the income accounting method used in this study provides a snapshot on the importance of charcoal in rural livelihoods, the informants' recall of yearly incomes and expenses may be inaccurate. Even though cross-checking of information provided was done, there is always the possibility of under reporting or exaggeration, especially on incomes (Dex 1995; Zhou 2000). Charcoal production has always attracted the "illegality tag", and many producers may have failed to disclose the full extent of their involvement (Mwesigye et al. 2011; Mosberg and Eriksen 2015).

5 Conclusions and recommendations

The role of charcoal production in rural communities has remained largely unknown, especially with respect to the different roles of charcoal production for different groups within communities. Based on the results of our household questionnaire among charcoal- and non-charcoal-producing households in semi-arid Kenya, we conclude that gender, land size and the number of food-scarce months are the most important determinants of engagement in charcoal production. Land size is an important determinant of engaging in charcoal production because of its uniformity in quality over the study area; thus, agricultural production is proportional to land size. Charcoal income is mostly spent on basic needs; thus, it has an important role in day-to-day rural livelihoods. Overall, charcoal making contributes on average 20% to the total household income in the study area, which is similar to other reported contributions in forest income studies in sub-Saharan Africa. A key conclusion of this study is that the role of charcoal production in livelihood strategies is highly variable between different groups within a community. Furthermore, whereas charcoal income has little chance of permanently removing households out of poverty, it plays a critical role as a "gap filler", diversification strategy or "last-resort" activity depending on other income sources.

While the woodlands in our study area can sustain the current levels of charcoal production on the short term, as based on estimates from an agent-based modelling analysis (Kiruki et al. 2019), there is a serious problem on the long term. Producers will have to adopt other livelihood strategies in the long run as the carrying capacity of the woodland

is expected to rapidly decline during the coming decades. However, it has been argued that sustainable charcoal production is potentially possible through improved woodland management, assisted regeneration and short rotation plantations in addition to legalization and formalization of charcoal production and trade (Mwampamba et al. 2013; Neufeldt et al. 2015). Such initiatives would guarantee charcoal makers a higher price and sustainability of production leading to better livelihoods and reduced poverty levels (Munthali and Murayama 2015).

Based on the significant role of charcoal income and the limited livelihood options in the area, we recommend a multipronged policy approach to address sustainable rural livelihoods. This includes a more explicit acknowledgement of charcoal production as a source of rural incomes, preferably within a more coherent policy framework governing the charcoal sector (Sander et al. 2013), which should also include the recognition and formalization of informal institutions (Wiersum et al. 2014). However, Jones et al. (2016) caution that formalization of the charcoal production sector has to be done with care, to ensure continued access of rural households to charcoal production as flexible income source.

Although there are significant challenges, charcoal production has the potential to be a local and low-cost income source that can contribute to poverty alleviation (Neufeldt et al. 2015). One of the challenges is that currently only 20% of the value of charcoal accrues to the producer in Kenya (Mwampamba et al. 2013). Furthermore, care should be taken to avoid a poverty trap situation associated with reliance on forest incomes. To avoid dependence on charcoal making, broadening the local livelihood base is crucial, for example, to include more incomes from business and skilled labour. This is especially important as dependence on agriculture suffers from low productivity, a situation comparable to other charcoal-producing regions (Woollen et al. 2016). Finally, as intensive charcoal production can have a detrimental effect on woodland status and regeneration, the sustainability of the charcoal sector needs to be improved, for instance through improved production technologies and active management of the woodland. Assisting and ensuring active participation of local, often disempowered, communities is necessary to introduce and sustain more sustainable management practices (Neufeldt et al. 2015).

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Appendix

See Tables 8, 9 and 10, Figs. 4 and 5.

Table 8 List of common goods and services and their monetary value

Item	Value (Ksh)
Hired labour	400/day
Maize (90 kg bag)	3000
Cowpeas/pigeon peas (90 kg bag)	4000
Honey (kg)	400
Millet/Sorghum (90 kg bag)	2500
Mung beans (90 kg bag)	8000
Certified maize seed (kg)	200
Certified mung bean seeds (kg)	250
Heifer (average price)	30,000
Chicken	300
Bull (average price)	45,000
Donkey (average price)	10,000
Jerrycan of water (20 litres)[3]	10
Charcoal bag (35 kg)	450
Firewood bundle (20 kg)	20
Land ploughing (per ha.)	7500

Table 9 Socio-economic variables used in OLS regression analysis

	Variable	Description
1	Roof type	Either grass or iron sheets (binary)
2	Gender	Male or female (binary)
3	Age	Years
4	Land size	Acres
5	Food scarcity	Months
6	Oxen plough	Present or absent (binary)
7	Motor bike	Present or absent (binary)
8	Bicycle	Present or absent (binary)
9	Solar panel	Present or absent (binary)
10	Distance to the game reserve	Metres
11	Distance to Mutha shopping centre	Metres
12	Distance to the main road	Metres
13	Distance to all roads	Metres
14	Land-use type	Farmland, transition woodland or woodland (binary)
15	Stay period	Years
16	Cultivated area	acres
17	Livestock	Tropical livestock units

Table 10 A comparison of asset holding between charcoal- and non-charcoal-making households

Attribute	Charcoal makers		Non-charcoal makers		*P*
	Range	Average	Range	Average	
Land holding (ha)	0.6–14.8	3.48	0.4–28	5.63	$P<0.05$
Cultivated area (ha)	0.4–4.8	1.3	0.28–8	1.85	$P<0.05$
Household income (Ksh)	10,420–325,700	79,800	4137–522,120	113,928	$P<0.05$
Livestock holding (TLU)	0.02–9.2	2.35	0.03–19.05	4.13	$P<0.05$

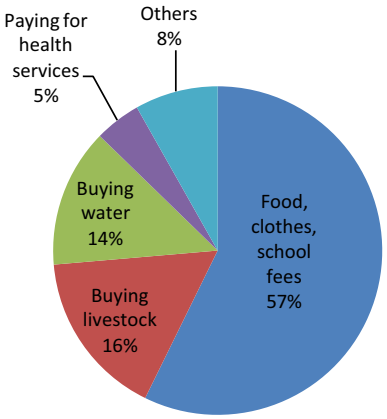

Fig. 4 A pie chart showing the main spending sources of charcoal income (charcoal-producing households)

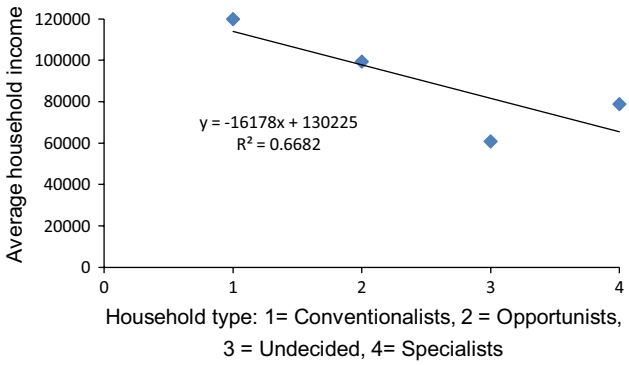

Fig. 5 Relationship between total income and level of dependence on charcoal income

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